

Effect of Seepage on Bearing Capacity of Strip Footings

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ABSTRACT: The influence of position of water table and magnitude of hydraulic gradient on the behaviour of a strip footing resting on a cohesionless soil is investigated by carrying out a series of finite element analyses and laboratory scale load tests. The results of finite element analyses and laboratory scale load tests are compared with those obtained from conventional mathematical models. It is observed that the load-settlement behaviour improves with depth of footing and depth of water table similar to the predictions of conventional mathematical models. The downward hydraulic gradient increased the effective stress within the soil and caused an increase in bearing capacity.

KEYWORDS: Water Table, Hydraulic Gradient, Finite Element Analyses, Bearing Capacity

I. INTRODUCTION

Bearing capacity of shallow foundations is a fundamental issue in geotechnical design and has been widely addressed. Many exact or established theoretical solutions exist for shallow foundations under uniaxial vertical load, pure horizontal load, pure moment centrally applied inclined load and eccentrically applied vertical loads ([1], [4], [12], [16], [17]). In general, most geotechnical analyses are treated deterministically, in which the soil medium is considered as a single homogeneous layer or a layered medium with uniform material properties in each layer based on "average" values of soil parameters. However, in nature, soil parameters generally show significant spatial variation in both vertical and horizontal directions, and the results of deterministic analyses are only expected values which may vary from actual performance of constructed facilities [3]. In most of the practical situations, the bearing capacity will be considerably influenced by the presence of adjacent footings [9]. Many researchers have carried out numerical and experimental work to study the mechanisms of failure and bearing capacity of soil in the past decade ([5], [6], [7], [8], [10], [11], [13], [14], [15] and [18])

The presence of water table has considerable influence on bearing capacity of a footing. In the classical theory, influence of water table is quantified by considering the reduction in unit weight of soil due to the submergence. In most of the recent studies the influence of position of water table is not considered. The bearing capacity will also be influenced by the hydraulic gradient of ground water wherever there is seepage. In this paper, the influence of position and hydraulic gradient of water table on bearing capacity of a strip footing is investigated by carrying out a series of finite element analyses using the software PLAXIS 2D and laboratory scale load tests. The parameters varied are depth of footing from ground level, position of water table and magnitude of hydraulic gradient.

II. LABORATORY SCALE LOAD TESTS

The experimental investigation was carried out at the Geotechnical Engineering Laboratory of LBS Institute of Technology for Women, Thiruvananthapuram.

A. MATERIALS USED

The foundation soil used is sand and its properties are given in Table 1.

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TABLE I
PROPERTIES OF SAND

Property	Value
Specific Gravity	2.65
Average dry unit weight (kN/m ³)	14.18
Friction angle ϕ°	31.2°
Cohesion(kPa)	0
Coefficient of permeability	1.07x10 ⁻⁴

B. EXPERIMENTAL SETUP

An inverted Tee Beam of flange width 100 mm is used as the model strip footing. The web of the Tee Beam is stiffened using MS angle sections. The loading tests are carried out in a loading frame fabricated with ISMB 300. The load is applied using a hand operated- mechanical jack of capacity 50kN. The applied load is measured using a proving ring of capacity 10kN. The settlement of the model strip footing is measured using two dial gauges kept diametrically opposite to each other. The model strip footing is placed exactly beneath the centre of loading jack to avoid eccentric loading. The figure of the test setup is shown in Figure 1 and photograph in Figure 2. The parameters varied are presented in Table 2.

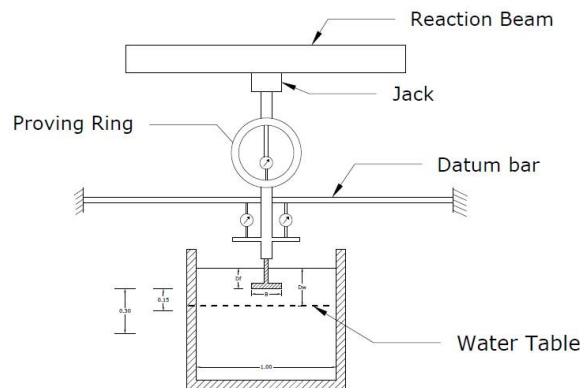


Fig 1. Test Setup



Fig 2. Photograph of Test Setup

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TABLE II
PARAMETERS VARIED

Parameter	Value
Depth of Footing (Df)	0, 0.5B, B
Depth of Water Table (Dw)	0, 0.5B, B, 2.5B
Hydraulic Gradient (h/L)	0.15, 0.3

Tests are also conducted for various hydraulic gradients. To impart a hydraulic gradient, the water is pumped through the inlet and taken out through outlets at different levels. The test setup with hydraulic gradient 0.15 and 0.3 are shown in Figures 3 and 4 respectively.

The inlet of water is kept at the level of model footing. There are two outlets for water; at 0.15m and 0.30m below the level of inlet. The width of test tank is one metre. To maintain a hydraulic gradient of (h/L)=0.15, water is pumped in through the inlet and taken out through the top outlet, keeping the bottom outlet closed.

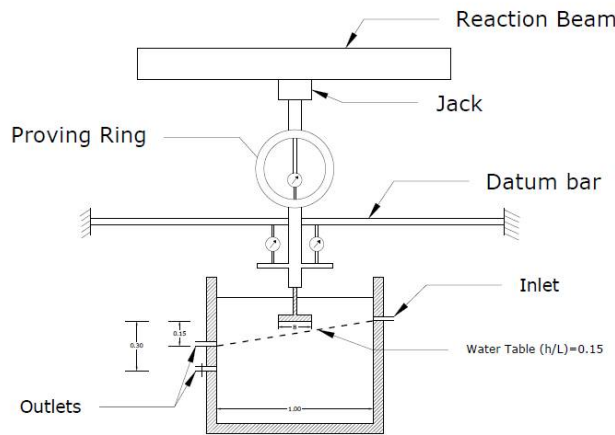


Fig 3. Arrangement for Hydraulic Gradient of 0.15

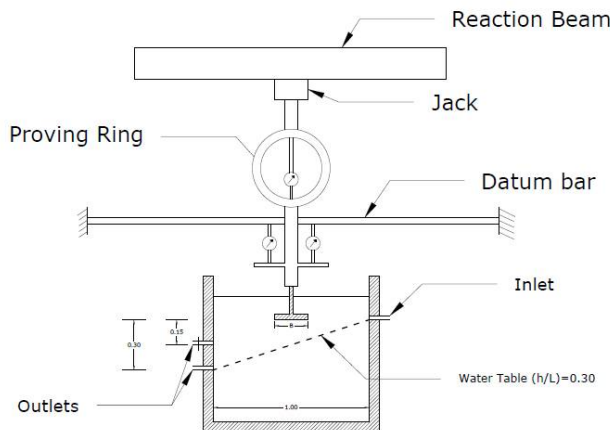


Fig 4. Arrangement for Hydraulic Gradient of 0.30

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Load test is carried out after steady state conditions are achieved. Similarly, for a hydraulic gradient of 0.3, the top outlet is closed and water is taken out through the bottom outlet. The photograph of outlets at different levels is shown in Figure 5.



Fig 5. Outlet for water at different levels

III. FINITE ELEMENT ANALYSES

Finite element analyses are carried out using the commercially available finite element software *PLAXIS 2D*. For simulating the behaviour of soil, different constitutive models are available in the FE software. In the present study Mohr-Coulomb model is used to simulate soil behaviour. This non-linear model is based on the basic soil parameters that can

be obtained from direct shear tests; internal friction angle and cohesion intercept. Since strip footing is used, a plain strain model is adopted in the analysis. The settlement of the rigid footing is simulated using non zero prescribed displacements.

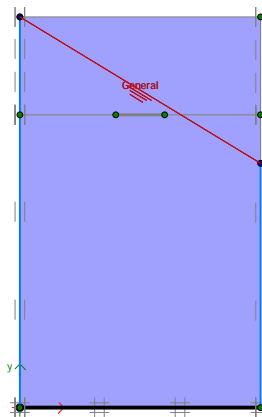


Fig 6. Geometry Model for water table with Hydraulic Gradient

The displacement of the bottom boundary is restricted in all directions, while at the vertical sides; displacement is restricted only in the horizontal direction. The initial geostatic stress states for the analyses are set according to the unit weight of soil. The soil is modelled using 15 noded triangular elements. Mesh generation can be done automatically. Medium mesh size is adopted in all the simulations. The size of the strip footing (B) is taken equal to that of model strip footing and the width and depth of soil mass are taken as 10B in all analyses. The geometric model with a hydraulic gradient in ground water is shown in Figure 6.

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IV. RESULTS AND DISCUSSIONS

The results obtained from finite element analyses and laboratory model tests are presented below.

A. EFFECT OF DEPTH OF FOOTING

The load-settlement behaviour obtained from laboratory model tests at various depths of embedment of footing, when soil is dry, is presented in Figure 7.

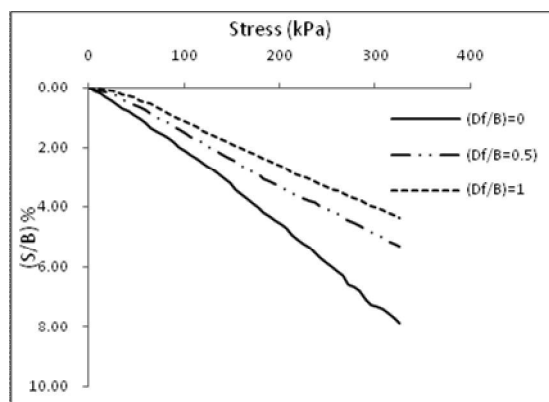


Fig 7. Load-Settlement Behaviour at Various depths of footing in dry sand

It is observed that as the depth of footing increases, the load-settlement behaviour improves similar to the predictions by conventional mathematical models.

B. EFFECT OF DEPTH OF WATER TABLE

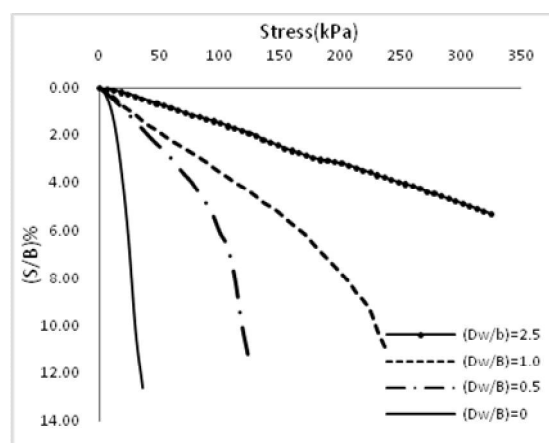


Fig 8. Load-Settlement Behaviour at various depths of Water Table

Figure 8 presents the load-settlement behaviour, obtained from laboratory model studies for various depths of water table from the ground level, when the depth of footing is equal to the width of footing. It is seen from the figure that as the depth of water table increases, the load-settlement behaviour improves as predicted by conventional mathematical models.

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C. EFFECT OF SEEPAGE

The effect of seepage on load-settlement behaviour is presented in Figure 9. The figure shows the behaviour when there is no seepage and with seepage for two values of hydraulic gradient.

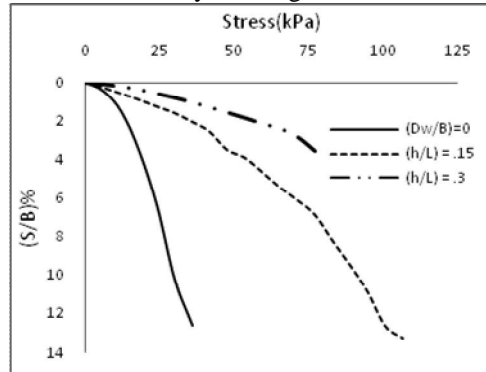


Fig 9. Load-Settlement Behaviour at various hydraulic gradients

It is seen from the figure that as the hydraulic gradient increases, the load-settlement behaviour improves. It is observed from the results of finite element analyses that, as the hydraulic gradient increases, the effective stress in soil increases. It causes an increase in shear strength of soil. The values of effective stress at the bottom of test tank obtained from finite element analyses are presented in table 3.

TABLE III
EFFECTIVE STRESS AT VARIOUS VALUES OF HYDRAULIC GRADIENT FROM FINITE ELEMENT ANALYSES

Cases	Effective stress at inlet (kN/m ²)	Effective stress at outlet (kN/m ²)
Df/B=0	6.736	6.738
h/L=0.15	6.823	8.355
h/L=0.3	6.382	9.587

It is observed that when there is no hydraulic gradient, the effective stress distribution is constant throughout the width of tank. As the hydraulic gradient increases, the effective stress at outlet region increases, whereas the effective stress at inlet remains constant.

V. CONCLUSIONS

Based on the results obtained from finite element analyses and laboratory scale load tests, following conclusions are drawn

- The load-settlement behaviour improves with depth of footing and depth of water table similar to the predictions of conventional mathematical models
- Downward seepage caused an increase in bearing capacity of the footing
- Downward seepage caused an increase in effective stress near the outlet. However the effective stress near the inlet is not affected by hydraulic gradient.

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